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Global change effects on biogeochemical processes of Argentinian estuaries: An overview of vulnerabilities and ecohydrological adaptive outlooks

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ABSTRACT

The aims of this work are to provide an overview of the current stresses of estuaries in Argentina and to propose adaptation strategies from an ecohydrological approach. Several Argentinian estuaries are impacted by pollutants, derived mainly from sewage discharge and agricultural or industrial activities. Anthropogenic impacts are expected to rise with increasing human population. Climate-driven warmer temperature and hydrological changes will alter stratification, residence time, oxygen content, salinity, pollutant distribution, organism physiology and ecology, and nutrient dynamics. Good water quality is essential in enhancing estuarine ecological resilience to disturbances brought on by global change. The preservation, restoration, and creation of wetlands will help to protect the coast from erosion, increase sediment accretion rates, and improve water quality by removing excess nutrients and pollutants. The capacity of hydrologic basin ecosystems to absorb human and natural impacts can be improved through holistic management, which should consider social vulnerability in complex human–natural systems.

1. Introduction

Global change, the synergic interaction of anthropogenic impacts with climate-driven changes, is already disturbing estuarine ecosystems. Not only projected higher temperatures but also human population growth, sea-level rise, ocean acidification, changes in wind and current patterns, heat waves, extreme hydrological oscillations (e.g., floods and droughts) and coastal storms will strongly alter the dynamic of nutrients and pollutants and their relation with biota in estuarine and coastal systems. Even if the emissions of CO_2 are mitigated, some of the projected climatic changes are inevitable, and adaptation strategies are crucial for the successful management of estuaries and coastal waters. Although considerable research has been carried out on the possible impacts of climate change, little work has been conducted on adaptation strategies. The adaptive capacity of socioeconomic systems in Latin America is very low, whereas their vulnerability to climate change is high (Mata et al., 2001). Furthermore, while developing countries carry a large part of the global impact of climate change, rising atmospheric greenhouse gas concentrations are mainly caused by industrialised countries (Mertz et al., 2009). Therefore, one of the major issues that policy makers, scientists and stakeholders are now facing is the assessment of complex and uncertain climate-driven responses.

Evaluating the effects of and adapting to climate change on estuarine systems is a methodological challenge. Interdisciplinary approaches are needed for the understanding of functional links between basin structure, morphology, and biogeochemistry of different estuaries and adjacent wetlands (Lara et al., 2002; Lara and Cohen, 2006). The ecohydrology concept offers a variety of tools for basin and coastal management under the combined effects of climate change and anthropogenic pressure (Wolanski et al., 2004; Kopprio et al., 2014). This concept was developed within the International Hydrological Program of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and is focussed on the integrated understanding of biological and hydrological processes at a catchment scale to create a solid basis for a

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cost-effective and holistic management of water resources (Zalewski, 2002). The aims of the program are to advance the integration of social, ecological, and hydrological research and to generate outcomes that enable the development of effective policies and practices. Ecohydrological management can be achieved by reversing the degradation and regulating the processes of water and nutrient circulation and energy flow in aquatic ecosystems, using the aquatic biota as water management tools and enhancing their social–ecological resilience. This multidisciplinary and adaptive strategy requires a clear knowledge of biogeochemical processes and their relations with estuarine hydrology to develop an efficient approach to basin management.

Estuarine systems are highly productive but vulnerable environments and are frequently under stress because of human population growth and socio-economic development. Although the coastline of Argentina extends over more than 4000 km, the number of estuaries is relatively low and their morphology and hydrography are highly variable (Piccolo and Perillo, 1999). However, a significant fraction of the Argentinian population is settled along the coasts of estuaries and will directly suffer because of climate-driven alterations of coastal ecosystems. To assess climate change impacts in the main Argentinian estuaries, this work provides an overview of the vulnerabilities and current stressors and suggests adaptive strategies based on an ecohydrological approach.

2. Vulnerability of Argentinian estuaries: an overview

The north extreme of the Pampa is the location of one of the most important estuarine environments of the continent: the Río de La Plata system (Fig. 1A). A microtidal estuary with a mouth of approximately 200 km width and an annual mean discharge of $\sim$22,000 $m^3\,s^{-1}$, this estuary is highly productive and sustains valuable fisheries from Argentina and Uruguay. The Río de La Plata is usually stratified but can sporadically be mixed within a few hours by strong winds and is also affected by the El-Niño-Southern-Oscillation (ENSO) on a long-term scale (Nagy et al., 2008; Acha et al., 2008). The river is strongly impacted by anthropogenic activities. The coastline is deeply modified by urban and industrial settlements and presents eutrophic characteristics with recurrent harmful algal blooms and development of hypoxia in bottom waters (Nagy et al., 2002; Gómez et al., 2009; Giannuzzi et al., 2012). The Río de la Plata estuary is also heavily polluted by aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs) (Colombo et al., 1989, 1990, 2005). In addition, several invasive species have been reported in the estuary, such as the golden mussel *Limnoperna fortunei* (Muniz et al., 2005; Boltovskoy et al., 2006), the veined rapa whelk *Rapana venosa* (Giberto et al., 2006; Lanfranconi et al., 2009), and the reef-builder polychaete *Ficopomatus enigmaticus* (Muniz et al., 2005; Borthagaray et al., 2006). Furthermore, toxic strains of *Vibrio cholera* have been detected in waters and planktonic organisms (Binsztein et al., 2004).

Other microtidal estuaries in the wet Pampa are those of the Samborombón and Salado systems, the Mar Chiquita lagoon, and the Quequén Grande River (Fig. 1B–D). The Pampa region is strongly impacted by agricultural activities and suffers recurrent cycles of flood and drought weakly related with ENSO oscillations (Kopprio et al., 2010). In this region, the warm phase of ENSO (El Niño) is generally associated with wet periods, while the cold phase (La Niña) is associated with dry periods. The most important stresses on the Pampean rivers are the discharge of untreated sewage, nutrients, heavy metals, pathogenic agents, pesticides and herbicides, as well as physical changes produced by dredging and canalization (Gómez and Licursi, 2001). The Samborombón and Salado systems (Fig. 1B) have been classified as hypereutrophic (Gabellone et al., 2005; Schenone et al., 2008) and contain heavy metal pollution (Marcovecchio, 2004; Gagneten et al., 2007) and OCPs above the permissible levels (Monserrat et al., 1994). The wetland area of Samborombón bay ($\sim$2440 km^2) was declared a Ramsar site due to its importance for biodiversity conservation and as a breeding area for several fishes and migratory birds. Mar Chiquita (Fig. 1C) is the only coastal lagoon of Argentina. It receives freshwater streams from the Tandilia system, and its wetlands are also an important Ramsar site. This water body of approximately 46 km^2 presents a high biodiversity and is a nursery area for marine fauna. Large discharges of pesticides, fertilisers, particulates, and dissolved metals originating from the intensive agriculture in the surrounding area are threats to the lagoon ecosystem (Menone et al., 2001; Marcovecchio et al., 2006; Beltrame et al., 2009). The Quequén Grande estuary (Fig. 1D) is a primary, coastal-plain, and partially mixed system in which water circulation is highly reduced, producing strong reductive and even anoxic conditions due to the presence of a step at the head of the harbour (Perillo et al., 2005). This estuary is principally influenced by the untreated sewage discharge of the Necochea and Quequén cities. The barnacle *Balanus glandula* and *F. enigmaticus* (Orensanz et al., 2002) are exotic species that modify benthic hard-substrate and have a significant ecological impact in this area.

South of the Pampa, in a semiarid region, is the location of the mesotidal estuary of Bahía Blanca (Fig. 1E). The system is a shallow funnel-shaped estuary (mean depth of 10 m) formed by a series of NW–SE channels separated by interconnected tidal channels, islands, extensive tidal flats, and low marshes (Perillo et al., 2001). The Bahía Blanca estuary is influenced by the cyclical wet and dry periods of the Pampa region. Nature preserves of various uses are located in the Bahía Blanca estuary, such as: Bahía Blanca, Bahía Falsa and Bahía Verde, which were created to preserve biodiversity, sustain fisheries and protect species at-risk for extinction. Despite this ecological importance, the system is strongly impacted by industrial activities and maritime traffic. The Bahía Blanca estuary is considered highly eutrophic (Freije et al., 2008) and is polluted by untreated sewage discharge (Lara et al., 1985; Biancalana et al., 2012; Dutto et al., 2014), hydrocarbons (Lara et al., 1995; Arias et al., 2010), heavy metals (Marcovecchio and Ferrer, 2005; Simonetti et al., 2012; Fernández-Severini et al., 2013), and organotin compounds (Delucchi et al., 2007). The invading species *B. glandula* and the copepod *Eurytemora americana* have caused changes in species richness and diversity (Hoffmeyer, 2004). Antibiotic-resistant *Escherichia coli* has also been isolated from the Bahía Blanca estuary (Baldini and Cabezalí, 1991).

The major Patagonian estuaries are those of the rivers: Colorado, Negro, Chubut, Deseado, Santa Cruz, and Gallegos (Fig. 1F–K). The Patagonian region is characterised by semiarid conditions and strong winds, and its rivers generally feature oligotrophic conditions (Depetris et al., 2005). Despite the low population density, the main pollution problems are related to sewage effluents, agricultural runoff, oil extraction and transportation, and metal wastes (Gil et al., 1999; Gaiero et al., 2003; Brunet et al., 2005). In Patagonian ports with high marine traffic or in areas where ship hulls are painted, the presence of organotin compounds and imposex incidence in gastropods have been reported (Bigatti et al., 2009). Toxic blooms of dinoflagellates and the consumption of bivalves during red tides have been responsible for toxicity in humans (e.g., Esteves et al., 1992), including some cases of human death along the Patagonian coast. The discharges of the Colorado, Negro, and Chubut rivers are influenced by dams for hydroelectrical energy. The estuary of the Colorado River (Fig. 1F) presents a deltaic form, is mesotidal, and is impacted by several hydrological works for irrigation, which modified its hydrological characteristics, such as salinity gradient and intrusion. PAHs and some heavy metals have been detected in its basin (COIRCO, 2012). The Asian clam *Corbicula fluminea* has been reported in the Colorado River (Cazzaniga, 1997).